A proposal to
California Department of Food and Agriculture
FERTILIZER RESEARCH AND EDUCATION PROGRAM

A. Cover Page

Project Title:

Soil biochar amendment to improve nitrogen and water management

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B. Executive Summary:

Problems to be addressed: Nitrogen (N) leaching from agricultural fields has been identified as the major cause for the statewide nitrate (NO_3^-) concentration increase in groundwater in California. Subsequent regulatory decisions have been or are in the process of being made by Regional Water Quality Control Boards that will impose restrictions to growers on the amount of N that can be applied to the field for specific crops. Nitrogen leaching is caused by the high mobility of NO_3^- in soil, which is formed from the quick hydrolysis of urea or oxidation of ammonium (NH_4^+) based fertilizer through nitrification. Although both NH_4^+ and NO_3^- are available forms for plant uptake, NH_4^+ can be more strongly retained by soil particles or organic materials. Nitrogen is one of the most complicated elements in its cycling. While N fertilizer provides the essential nutrient for crops it is also the source of several active N compounds that directly impact the environmental quality. Ammonia (NH_3) has several detrimental effects on human health and counts for the largest mass loss in gaseous form through volatilization from soil. Nitrate leaching is difficult to prevent in irrigated agriculture because growers target the highest yield when applying N; N and irrigation water are always applied higher than the crop demand which leads to NO_3^- leaching. Effective N management relies on better understanding of all N transformation and transport processes in the efforts to increase N use efficiency and reduce N loss to the environment. Most studies have focused on part or some of the N cycling aspects. Systematic and integrated approach is critically needed.

Biochar, produced from organic materials at high temperature under limited oxygen, has shown the benefits in carbon sequestration and improvement on soil physical, chemical and biological properties as well as mitigating environmental contamination problems. Numerous studies have also shown potential benefits of biochar in increasing N retention and reduced N leaching and gas emissions. However, variabilities in observed biochar effects are large among studies with many that show no benefits. Adsorption and delaying N transformation from urea and NH_4^+ based fertilizers to NO_3^- are the two major mechanisms of biochar to increase N retention or the availability for plant uptake in soil, leading to increased N use efficiency (NUE) and reduced N leaching (provided no excess irrigation or precipitation) and gas emissions. Biochar was shown to increase soil water holding capacity that increases water use efficiency and thus reduces leaching loss. There are large gaps in our understanding of what important mechanisms biochar products possess to interact with N or to alter the dynamics, and what properties of biochar determine the integrated benefits as well as the feasibility for growers to use in crop production.

Objectives: The goal of this study is to determine the overall benefits and practices of using biochar as a soil amendment in N and water management in vegetable crop production systems. Specific objectives are:

1. To determine effects of soil amendment with biochars produced from different feedstocks found in the San Joaquin Valley of California on adsorption capacity for NH_4^+ and NO_3^- and N transformation (urea hydrolysis and nitrification) rates as well as soil-water retention.
2. To determine effective amendment rate of biochar products and irrigation rates on crop response and N fate under field conditions.

Research approach: Both laboratory and field studies will be utilized to achieve the project objectives. For objective 1, laboratory studies will be carried out to characterize biochar products (e.g., surface area, pore size, chemical composition) made from different feed stocks, determine adsorption capacity for N species (NH_4^+ and NO_3^-) onto biochar and amended soil, and determine N transformation (urea hydrolysis and nitrification) kinetics affected by biochar, as well as soil-water retention functions affected by soil amendment with biochar. Six biochar products will be prepared for this study representing different feedstocks and/or pyrolysis conditions. The feed stocks will include tree pruning materials and/or those pulled out from old orchard (stone fruits, grapevines, almonds, and tree nuts) as well as nutshells after processing (almonds, walnuts, pistachios). The type of biochar, soil types (varying in texture and soil organic matter), soil water content (air-dry to saturation), and temperature (5–45°C) on N adsorption maxima and transformation rate in soil will be determined. The key parameters of biochar and important soil/environmental factors affecting N adsorption and transformation will be determined. Two promising biochar products in N retention will be selected for field tests.

For objective 2, two field experiments will be conducted to test incorporation of biochar to improve NUE and to reduce N losses to the environment for irrigated vegetable crops. Treatments will be selected among biochar amendment rate (e.g., 0, 25, and 50 t/ha) and irrigation level (e.g., 50, 75, and 100% of a reference which provides sufficient water for plant growth). Both field trials will be carried out at the USDA station in Parlier, California where research fields are available for the project. A split-plot design with irrigation levels as the main treatment and biochar as the sub-treatments in three replications (plot size: 20 m long × 2 m wide with doubled beds) will be used. Two vegetable crops (e.g., bulb onion and pepper) will be chosen for the field experiments using drip irrigation/fertigation system. Urea and ammonium nitrate (AN) will be used for fertilization. Vegetable crops are selected because their relatively shallow root zone presents more challenge in N management and are prone to more N leaching compared to perennials. Field monitoring will include continuous soil water content measurement using sensors at different depths in the root zone, weekly sampling for N concentration in soil pore water, NH_3 (the major gaseous form in N volatilization loss) volatilization rates, and biweekly measurements on plant growth and N uptake during growing season. In addition, soil samples in the rooting zone will be collected in early, middle, and later growing seasons from the field to determine N quantity and speciation that related to fertilization schedule or events. At harvest, crop yield, plant N uptake, NUE, soil N status change, and total N loss will be determined. All data will be statistically analyzed. Effective biochar material and application rate that do not compromise crop yield as well as costs involved will be determined.

Project evaluation. The project success can be evaluated by 1) increased knowledge on the mechanisms of biochar affecting N dynamics and water retention in soil; 2) biochar products and rate that increase NUE and crop yield while reducing losses; 3) data on how irrigation level affects plant growth and N leaching in biochar amended soil; and 4) estimated costs for biochar amendment for effective N management.

Audience: The project information will be of value to growers, farm advisors or consultants, biochar suppliers, and regulatory agencies or policy makers as well as researchers. Although the target crop is vegetable crops, the results will have great implications for all others. With more agricultural orders being established in different regions across the state in addressing the groundwater N problem, biochar is a promising solution and can be easily adopted.

C. Justification

Problems to be addressed:

Nitrogen (N) loss from agricultural fields is identified as a major source of the statewide nitrate (NO_3^-) concentration increase in groundwater (Nightingale 1972; Harter and Lund, 2012). To address existing and potential water quality issues, Agricultural Orders, such as No R3-2012-0011) have been issued by the California Regional Water Control Board Central Coast Region (CRWCB-CCR, 2012). A similar order (SWRCB/OCC Files A-2239(a)-(c)) has been proposed on February 8, 2016 by the State Water Board for the Eastern San Joaquin River Watershed, which covers 1 million+ acres of irrigated lands. These orders require growers to comply with the terms and conditions to ensure that agriculture would not contribute to the exceedance of water quality standards including groundwater contamination from nitrate leaching. Mandated reporting, including cropping system, N application, N use efficiency (NUE), etc., and a proposed tax on fertilizers are among many requirements that growers will face. To sustain the agriculture production, new strategies and practices that increase NUE and minimizing leaching loss are urgently needed to provide growers with a tool to comply with the new regulations.

Nitrogen input is essential for crop production and synthetic fertilizers are used in large quantities in most conventional and intensive farming operations. Synthetic fertilizers are in the form of urea, NH_4^+, and NO_3^- that are readily available to plants after incorporation into soil. Upon application to soil, urea is subject to fast hydrolysis to NH_4^+, which can be further oxidized to NO_3^- (nitrification) in most agricultural fields (unflooded conditions). Although both NH_4^+ and NO_3^- are available forms for plant uptake, NH_4^+ can be adsorbed or retained, but little adsorption of NO_3^- has been observed in soil (Kothawala, and Moore. 2009; Hollister, 2011). Much of the N fertilizer applied to soil is lost through leaching to groundwater or gaseous emissions to the atmosphere causing environmental damage and human health risks (Galloway et al., 2008). Groundwater N contamination is mainly caused by the highly mobile NO_3^-, which is transported to the groundwater by water percolating below the root zone of agricultural field (Letey and Vaughan, 2013. Thus, soil type, crop, and irrigation as well as N application are important factors affecting N leaching.

Ammonia (NH_3) is one of the major gaseous losses that can reach as high as 30% from anhydrous ammonia during furrow and border-check irrigation (Pettygrove, 2008). Immediate irrigation with 16-19 mm of water 1 day after urea based fertilizers applied at rate up to 200 kg N ha^{-1} appeared to result in a low range of NH_3 volatilization (0.1-4.0% of total N applied) in strip-till corn production systems for 2 years (Jantalia et al., 2012). These data suggest N volatilization loss is also highly affected by irrigation practices. High NH_3 loss is caused by a chemical reaction shifting from ammonium (NH_4^+) to NH_3 at high pH ($NH_4^+ + OH^- \rightarrow NH_3\uparrow + H_2O$). High soil pH, low soil water content, and surface application of fertilizer would all favor NH_3 volatilization. Surprisingly the literature is very limited on NH_3 volatilization measurements from current drip irrigation/fertigation practices in California agricultural fields. Increasing N retention and delaying hydrolysis of urea and oxidation of NH_4^+ to NO_3^- from fertilizer applications would increase the residence time of available N for plant uptake. Leaching and gaseous N losses (especially NH_3 volatilization) are all significant and must be considered simultaneously in N management for developing effective field practices to increase NUE.

Research to evaluate N dynamics including all these important pathways in a cropping system is extremely limited although essential for making sustainable decisions on N management.

Biochar, a highly porous material produced from various organic biomass at high temperature under limited oxygen, has shown a positive outcome in carbon sequestration and many potential agronomic benefits; yet there are many unknowns on soil nutrient retention and N cycling (Lehmann, 2007; Clough et al., 2013). Biochar can improve soil physical, chemical, biological properties, and/or improve crop production (Kloss et al., 2014) as well as immobilizing soil contaminants (Ahmad et al., 2014; Wang et al., 2014, 2015, 2016). Biochar has shown to reduce N_2O emissions (Singh et al., 2010; Ahmad et al., 2013). One of our most recent studies showed that a biochar produced from coconut-shell feedstock reduced N_2O emissions by 73% although N transformation (hydrolysis and nitrification) rate was not affected (Cai et al., in press). To test the hypothesis that adsorption of NH_4^+ plays the key role in N retention, we determined that the three biochar products all exhibited a linear adsorption isotherm for NH_4^+ (Fig. 1), but little adsorption for NO_3^- (Gao, unpublished data). Although many studies have shown that biochar reduced N leaching (Singh et al., 2010; Yao et al., 2012), NH_3 volatilization (Steiner et al., 2010; Mandal et al., 2016), and N_2O emissions (Singh et al., 2010; Cai et al., in press), variabilities among studies are large with some showing that the effects can also be negative, neutral, or short lived (e.g., Xing et al., 2015; Nelissen, 2013; Iqbal et al., 2015). Saarnio et al., (2012) observed that biochar addition indirectly affected N_2O emission via soil moisture and plant N uptake. There are significant knowledge gaps in understanding what mechanisms and biochar properties are playing the key roles in altering N dynamics. Further every aspect of N dynamics in agronomic systems is affected by water movement or irrigation, which not only directly affects N transport but also all N transformation processes. Integrated research to quantify N losses while simultaneously developing management practices using biochar amendment for the irrigated agricultural production systems in the San Joaquin Valley (SJV) of California is very limited and this project is to fill this major gap.

FREP mission and research priorities

This project addresses the priority area of FREP: The effect of biochar on nutrient management. Using a systematic and integrated approach, the proposed project is to increase our understanding on the interaction between biochar and nitrogen including major mechanisms and processes affecting the fate of N fertilizers applied to soil followed by field determination of effective biochar materials and application rate that increase plant uptake and reduce leaching and volatilization losses. Biochar products from different feedstocks from California orchards will be prepared, characterized, and selected for field tests. Thus this project will also provide the information for the biochar industry to produce effective products. Data on plant uptake, major N losses, leaching potential, NH_3 volatilization as well as improvement on soil properties and water movement will all be measured in order to determine effective biochar products and amendment rate from which costs can be estimated and evaluated as a practical solution for the growers. Vegetable cropping systems will be studied as they present more challenges in N management due to shallow root zone compared to perennial crops. Particularly, as one of the most significant factors affecting the fate of N, irrigation will be included in the field tests of this project, leading to the development of effective biochar amendment practice for irrigated agriculture in the SJV. Due to the many benefits at a reasonable cost, biochar amendment can easily be adopted. Thus, this project will directly contribute to the FREP mission: to advance the environmentally safe and agronomically sound use and handling of fertilizing materials.

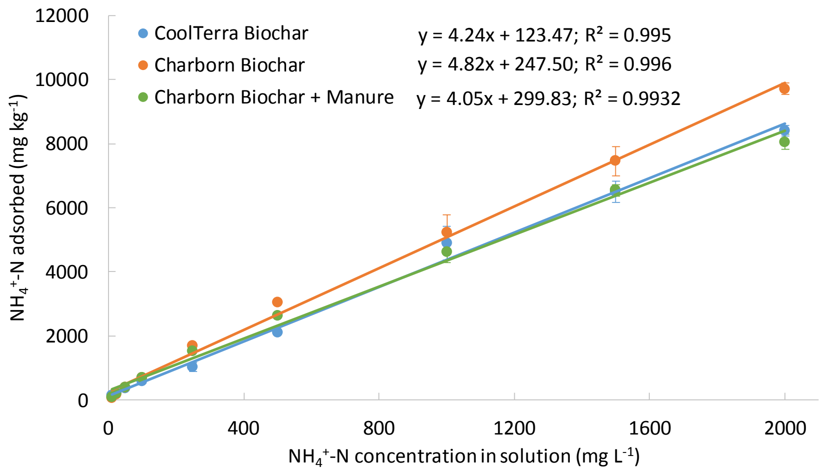

Figure 1. Adsorption of NH_4^+ by biochar products. Feed stocks for CoolTerra (CoolTerra, Camarillo, CA) and Charborn (Charborn LLC, Salinas, CA) biochars were coconut shell and wood materials, respectively (Gao, unpublished data).

Impact and long-term solution:

Nitrogen management will be a continuing challenge because high yields and maximum benefits will always require application of more N to soil than is removed by the crop (Letey and Vaughan, 2013). There are significant knowledge gaps in developing effective agronomic, economic, and environmentally-sound practices for sustainable agricultural production in California and this project is designed to fill the major knowledge gaps and conduct field studies using biochar amendment. This project will have long-term impact not only in the SJV and across the state, but also for agricultural production around the world because biochar as a soil amendment has been gathering momentum worldwide in pursing solutions to the global warming by carbon sequestration as well as protecting natural resources and improving soil productivity. Further, soils in the SJV are on a declining trend in soil organic matter (SOM) because of the arid to semiarid climate. Biochar amendment will be effective in improving soil health and soil productivity that will lead to a sustainable production system. This project will gain critical knowledge and field data on biochar as a practice, the important steps for achieving the long term goal – sustainable agriculture.

Related research, contribution to knowledge base, and grower use

Since 2000, the project PIs have been developing knowledge and practices for efficient use of water and N in field studies to search for solutions to the increased water shortage for agriculture. A 5-year field project for establishing a productive pomegranate orchard has just been completed from which N requirement and N_2O emissions were measured. Results indicate that N_2O emissions are significantly affected by irrigation method. We determined that a biochar product (CoolTerra, Camarillo, CA, USA) from coconut-shell feed stock significantly reduced N_2O emissions in laboratory experiments (Cai et al., in press). However, a lab study and an on-going field tests on an industrial biochar product from wood feed stock did not appear to have significant effects on NH_3 and N_2O emissions as well as downward movement of N in soil profile, but irrigation level showed more impact during onion growing season. All our observations support the concerns by FREP in the priority on biochar research. Thus we are proposing this systematic and integrated research project to fill in the important knowledge gaps using laboratory experiments to reveal the important mechanisms/processes and field studies to test performance of biochar product for effective N management. This project will result in a significant increase of knowledge and development of agricultural practices to use biochar for improving NUE and reduce the negative impacts of N fertilizers on the environment while not compromising crop yield. This project will identify effective biochar products made from local feed stocks and costs will likely be acceptable. With agricultural orders being established in different regions across the state in addressing the groundwater N problem, biochar is a promising solution and can be easily adopted because of many agronomic benefits.

D. Objectives

The goal of this study is to determine the overall benefits and practices of using biochar amendment to improve N and water management in vegetable crop production systems. Specific objectives are:

- To determine effects of soil amendment with biochars produced from different feedstocks found in the SJV of CA on adsorption capacity for NH_4^+ and NO_3^- and N transformation (urea hydrolysis and nitrification) rates as well as soil-water retention.

- To determine effective amendment rate of biochar products and irrigation rates on crop response and N fate under field conditions.

E. Work Plans and Methods

Both laboratory and field experiments will be carried out for this project. For the first year, we will focus on laboratory studies to prepare and characterize biochar products (e.g., surface area, pore size, chemical composition, etc.) made from different feed stocks, determine adsorption capacity for N species (NH_4^+ and NO_3^-) onto the biochar and amended soils, and determine N transformation (urea hydrolysis and nitrification) kinetics in biochar amended soils as well as soil properties and water retention functions affected by biochar. Three soil types ranging in soil texture and SOM will be used for these determinations. Effective biochar products in retaining N will be further tested in field determinations during the second and third year. Two field experiments will be conducted to determine effects of biochar materials, application rate, and irrigation levels on plant uptake, NUE, and major N losses (leaching, and NH_3volatilization) for two important vegetable crops in the SJV. All project information will be presented to growers at a number of local meetings, field days, and through various UCCE outreach activities and websites. The timeline and activities are summarized in Table 1.

Biochar preparation and characterization. Six biochar products will be prepared in ARS research facility and/or by Charborn, LLC or other companies. The products will represent different feedstocks and/or pyrolysis conditions. The feed stocks will be tree pruning materials and/or those pulled out from old orchard (stone fruits, grapes, almonds, and tree nuts) as well as nutshells after processing (almonds, walnuts, and pistachios) in CA. These biochar materials will be characterized for following: surface area (SA), pore size distribution, and chemical composition including elements and volatile matter. These parameters will be determined by commercial company because sophisticated methods and equipment involved. Other important physical properties such as particle size distribution, bulk density, and water holding capacity that will affect the interaction of biochar with soil and plant growth will also be determined similarly to soil samples using the methods described in Dane and Topp (2002). These parameters will be used to examine effects of biochar on N retention and dynamics in both laboratory and field experiments described below. A biochar product, CoolTerra (Camarillo, CA, USA) will be used as a reference material in this study because it has been shown to be effective in reducing N_2O emissions in comparison with three other biochar products (Gao, unpublished data). CoolTerra biochar is derived 100% from coconut shell feedstock, pyrolyzed at 550°C in controlled kiln-based operations, and then underwent a proprietary post-production treatment to neutralize the pH and remove residual elements like VOCs, dioxins, or furans.

Laboratory experiment 1. Determine NH_4^+ adsorption isotherm and adsorption capacity onto biochar and biochar-amended soils. All biochar products will be tested for adsorption isotherm and capacity for NH_4^+. Nitrate will be examined in selected samples because NO_3^- adsorption is not expected to contribute to significant N retention based on our own and many other studies. The effects of biochars from different feed stocks, amendment rates (at equivalent dry weight 0–50 tons/ha), soil types (varying in texture and SOM), soil water content (air-dry to saturation), and temperature (5–45°C) on NH_4^+ adsorption maxima or adsorption coefficients using different adsorption models, such as linear, the Langmuir or Freundlich equations will be determined. Three important soil types in California varying in soil texture and SOM will be selected for these determinations.

To determine adsorption isotherm or capacity of biochar materials and amended soils, a range of solution NH_4^+ concentrations (ranging from 0 to 1000 mg/L) will be used to determine adsorbed NH_4^+ at equilibrium. This will be done by adding biochar into a known amount of NH_4^+ solution and observing NH_4^+ concentration decreases in the solution over time. The time at which there is no further concentration change in the solution phase is the time when equilibrium is reached. Glass vials (20 mL) will be used in all adsorption experiments. All tests will use 0.1 g of biochar at 1:100 (w/v, biochar/solution) ratio. Selected biochar products plus CoolTerra biochar will be applied to the three soils and the same determination will be made as the pure biochar materials except using 1:10 soil/solution ratio. Sterilized and unsterilized soils will be compared to determine the degree of NH_4^+ oxidation during the adsorption experiment. At equilibrium, solution N concentration and species will be analyzed (see below). The adsorption isotherms will be graphed by plotting the amount adsorbed versus the solution phase concentration at equilibrium. Different adsorption models, such as linear, Langmuir, or Freundlich equations (Foo and Hameed, 2010), will be fitted to the data. Relationships between adsorption capacity with soil properties (e.g., soil texture, SOM, CEC) and biochar properties will be examined using regression analysis. The adsorption data will provide information on how adsorption process affects soil retention for NH_4^+ and help select effective materials and amendment rate for field tests. The effective amendment rate will be estimated based on what N application rate will be used in the field, biochar adsorption maxima for NH_4^+, and costs.

Laboratory experiment 2. The effects of biochar on N transformation in soil will be examined in incubation experiment. Biochar materials with high adsorption capacity for NH_4^+ will be selected from materials tested in the Laboratory Experiment 1 to examine how N transformation from urea or NH_4^+-based fertilizers to NO_3^- will be affected or delayed. Treated soils will be incubated following similar procedures described in Cai et al., (in press). Air dry soil (3.0 kg oven dry basis) will be weighed into 4 L high density polyethylene (PE) containers (20 × 20 ×10 cm) with lids (Rubbermaid Commercial Products Inc., Winchester, VA, USA). A urea or NH_4^+-based fertilizer (e.g., UAN) stock solution (32.16 g L^{-1}) will be prepared with deionized (DI) water. A known volume of the solution will be diluted with DI water before spraying onto the soil to simultaneously achieve the target N application rate and the desired soil water content. The soil will be incubated at various temperatures (5–45 °C). Soil samples will be collected at 0.5, 1, 2, 3, 5, 7, 10, 15, 20, 30, 45, and 60 days, extracted with 2M KCl [shaken for 1 h at 1:2.5 (w/v) ratio], and analyzed for mineral N species .

Soil suspension or extractants will be immediately filtered and analyzed for mineral N species (NH_4^+, NO_2^-, and NO_3^-) by colorimetric methods (Mulvaney, 1996) using an Astoria 2 Analyzer (Astoria-Pacific Inc., Clackamas, OR). Soils will be characterized for general properties, pH, EC, CEC, SOM, texture, available N, total N, and other nutrients using methods employed in UC Davis Analytical Lab (http://anlab.ucdavis.edu/) , Total soil N (mineral N plus organic N) and C will be determined using combustion methods with a LECO TruMac® CN Macro Analyzer (LECO Corporation, St. Joseph, MI).These parameters will identify urea hydrolysis and nitrification rate that will be estimated by curve-fitting (similar to adsorption isotherm experiments) and compared among amendment rate, under different soil, and environmental conditions.

Laboratory experiment 3. Determine pH, salinity, cation exchange capacity (CEC), and water retention functions of biochar-amended soils. Laboratory measurements will be made to determine the solution pH, changes in CEC, and electrical conductivity (EC) using 1:1 soil/water extracts from the biochar-soil samples. Five biochar-amendment rates will be used for each combination of the three soil types and six biochar types. The proposed five amendments rates are 0, 1, 5, 10, 30% biochar (by volume) mixed with the soil. Due to the time-consuming nature, water retention measurement will be carried out for only the 0, 5, and 30% amendment rates using the pressure plate method. The procedure involves saturating the samples and then placing them in the pressure chamber at selected pressure settings until equilibrium. By weighing the samples at different pressure settings the paired volumetric water content and pressure will be obtained. The data will be used to fit the water retention functions reported in the literature such as the one by van Genuchten (1980). Parameters for describing the water retention function have direct applications to predicting water and nitrate movement in the soil.

Field studies

Two field experiments will be conducted to test incorporation of biochar to improve NUE and reduce N losses to the environment. Both field experiments will be carried out at the SJVASC where research fields are available for the project. A split-plot design in three replications will be used for both field trials. The main treatments will be irrigation and the sub-treatment will be biochar. Plot size will be 20 m long × 2 m wide doubled beds. Two vegetable crops (tentatively onion and pepper) will be planted and irrigated with surface drip. Both crops are commercially produced major vegetable crops in the SJV of California.

Field experiment 1. Three biochar treatment rates (0, 25, and 50 t/ha) and three irrigation levels (100%, 75%, and 50%) will be tested. Tentative treatments will include:

1. Control: No biochar,100% irrigation
2. 25 t/ha biochar, 100% irrigation
3. 50 t/ha biochar, 100% irrigation
4. No biochar, 75% irrigation
5. 25 t/ha biochar, 75% irrigation
6. 50 t/ha biochar, 75% irrigation
7. No biochar, 50% irrigation
8. 25 t/ha biochar, 50% irrigation
9. 50 t/ha biochar, 50% irrigation

All treatments will be applied with the same fertilization regime (e.g., base fertilizer urea and UAN during the growing season) based on current growers' practices and references to provide sufficient but not excessive N and other nutrients (P, K, and micronutrients).

Field experiment 2. The second field experiment will have two purposes: 1) confirm the first field experiment findings for a different crop; and 2) incorporate two or three biochar products. Thus treatments will be modified from the Field Experiment 1. Irrigation level compromising yield will be dropped or modified. Total 8-9 treatments will be included.

For both field experiments, sampling and measurement will be similar: plant growth, NH_3 volatilization, and NO_3^- leaching water concentration during the growing season; and plant N uptake, yield data, and soil N changes by sampling before planting and after harvest. In addition, soil samples in the rooting zone will be collected in early, middle, and later growing seasons from the field to determine N quantity and speciation that related to fertilization schedule or events. Sampling for NH_3 volatilization, and NO_3^- leaching in water will be conducted daily following each fertilization event for about two weeks and once or twice weekly thereafter. Irrigation water N will be monitored for determining total N input. For N uptake, biweekly plant samples will be collected from each treatment, dried, ground, and analyzed for total N. By harvest, the NUE by crops, leaching risks, and NH_3 volatilization loss as percentage of total N applied as well as soil N changes will be estimated or determined and compared among the various treatments to determine effective N management practices under the field conditions. Specific sampling procedures are described below:

Irrigation water N and leachate N: Irrigation water will be collected several times during the growing season and total mineral N and N species will be determined similarly to that for the soil extracts in laboratory experiments. Leachate below the soil rooting zone will be collected using porous ceramic cups (Curley et al., 2011) and analyzed for NO_3^-.

Ammonia volatilization will be measured using a semi-static (open) chamber described in Jantalia et al. (2012). The chamber was constructed from a clear polyethylene terephthalate (PET) soda bottle (~10 cm id x 26 cm h) with the bottom removed, which was positioned 2 cm above the top opening with supporting wires to prevent dust/rain falling into the chamber. Inside the chamber is a long wire with a hook hung from the chamber top and a round wire basket on the bottom end to hold a 60-ml plastic jar containing an acid solution. A long strip of foam with one end soaked into the acid solution was pulled up and fastened to the wire top. The increased surface area by the foam strip is to increase the trapping efficiency for the NH_3. The NH_3 is trapped by dissolving into the acid solution on the foam to form NH_4^+. The NH_4^+ will be washed or extracted several times with the acid solution to a known volume and analyzed using the method described above for NH_4^+-N. The semi-open chamber type has a recovery about 68% compared to the NH_3 loss determined by ^{15}N method, which is used to calculate NH_3 volatilization from the measured. The method is reliable and relatively easy for field measurement. Each sampling is usually conducted for 24 hours. Ammonia volatilization rate is calculated by the total amount of NH_3 trapped into the acid solution and divided by the sampling time and surface area. Total or cumulative NH_3 volatilization will be estimated for a crop growing season.

Data analysis (apply to both Field experiment 1 and 2): A split plot mixed model will be used for data analysis on plant N uptake, NUE, yield, and cumulative N loss to the environment. Irrigation, biochar, and their interaction will be the fixed effects and the replications (blocks) and irrigation or biochar by blocks will be random effects. Means will be analyzed using 95% confidence intervals for the irrigation and biochar main effects as well as interactions between the irrigation and biochar, and linear and quadratic contrasts for the fixed effects. Costs associated with the use of biochar will be estimated at different rates.

Table 1. Project Plan

Timeline (Month/Year)	**Activities**	**Performed by**
Jan–Mar, 2017	Establish project agreement with CDFA-FREP. Hire the project technical support personnel. PI to communicate with all project participants and develop specific plans. Locate different feed stocks and prepare biochar products in ARS and/or by Charborn, LLC.	USDA-ARS ANR-UCCE Charborn, LLC
April–Dec, 2017	Characterize biochar products for surface area, pore size distribution, chemical composition etc. Conduct laboratory experiments to determine adsorption capacity or coefficient (Kd) for NH_4^+ and NO_3^-; N transformation from urea or NH_4^+ based fertilizer; soil properties, and water retention characteristics, effects of environmental factors, soil type, temperature, and soil water content.	USDA-ARS

Oct–Dec, 2017	Select effective biochar products and produce large quantity for field experiment. Prepare the field: test soil for N and if N level is not uniform in the field, grow cover crop.	USDA-ARS Charborn, LLC
Jan–Dec, 2018	Present research results at the CA-ASA Plant and Soil Conference, local and FREP meetings Establish the first field experiment: prepare the field, design field layout, build irrigation and fertigation system, apply treatments, apply base fertilizer, planting. Install field equipment (NH_3 volatilization chambers, pore water samplers). Collect samples for NH_3 volatilization, and soil pore water nitrate. Do biweekly measurement on plant growth and plant uptake. Collect soil, plant, and irrigation water samples several times during the growing season. Measure crop yield and collect all final soil and plant samples at harvest. Perform laboratory analysis for NH_3 volatilization samples, N species in soil and in pore water, and total soil and plant N. Conduct statistical data analysis. Conduct field days. Prepare annual report.	USDA-ARS ANR-UCCE
Oct–Dec, 2018	Prepare biochar and field for the second field experiment similarly as for the first field experiment.	USDA-ARS Charborn, LLC
Jan–Dec. 2019	Present the project results at the CA-ASA Plant and Soil Conference for the 2^{nd} year research findings. Establish the second field experiment with a second crop. Modify treatments if necessary to confirm first field tests towards developing practices for growers' adoption. Field equipment, sampling, and analysis will be similar to the first field experiment. Conduct statistical data analysis. Estimates costs for effective biochar amendment. Conduct field days and present at different local meetings. Present the project findings at a professional meeting such as ASA-CSSA-SSSA annual meeting. Prepare final project report.	USDA-ARS ANR-UCCE

F. Project Management, Evaluation, and Outreach

Management. Dr. Suduan Gao and Dr. Dong Wang (USDA-ARS, Parlier, CA) are the project investigators. Gao will be responsible for the overall project planning, timely progress, and preparing reports. With the expertise on soil and environmental chemistry, Dr. Gao will also be responsible for the lab studies (Objective 1), field measurements on NH_3 emissions, soil pore water N, and all laboratory analyses. With the expertise on soil physics and agricultural engineering, Dr. Wang will take the lead and supervise all work related to irrigation and soil water characterization as well as plant growth and yield measurements. Both PIs will work closely to establish the field experiments. Mr. Turini, Farm Advisor in Fresno County, will provide assistance in plant selection and field operation. Mr. Kurt Hembree will provide assistance in weed management for the crops. Both Mr. Turini and Mr. Hembee will conduct extension activities including assisting the PIs to conduct field days and presentations at different forms of local meetings for growers. Mr. Brinton, Charborn, LLC, will provide the assistance to produce the biochar products, especially commercial grade in large quantities for conducting field tests. All project participants will be involved in presenting the project results to stakeholders or industry meetings (e.g., biochar conference).

Evaluation. This project will be evaluated by 1) increased knowledge on the mechanisms of biochar affecting N dynamics and water retention in soil; 2) biochar products and rate that increase NUE and crop yield while reducing losses; 3) data on how irrigation level affects plant growth and N leaching in the presence of biochar; and 4) estimated costs for biochar amendment. The progress will also be monitored by reports, presentation to growers, regulator/policy makers, and others associated with California agriculture, and peer-reviewed journal publications.

Outreach. The project findings will be presented at the annual California Plant and Soil Conference each year, FREP meetings, local growers meetings whenever appropriate, and industry. At least one field day (mostly for growers and consultants) per each field experiment (minimum of two) will be held during summer and/or fall at the field experimental site. The research findings will be presented to various local meetings or various forms of extension activities through UCCE and the biochar industry via presentations at the U.S. Biochar Conference.

G. Budge Narratives (USDA-ARS, Parlier)

Total Grant Funds ($214,854.00):

Majority of the requested fund is to support one full time project personnel, whose role is critical to data collection in the lab and field to achieve the project objectives. Without this support, proposed project plan won't be possible to achieve. This project will need more personnel support that will come from our existing resources of the USDA research unit (see in-kind contribution at the end of the budget). Some lab supplies are also requested. All essential equipment needed for this project is available.

PERSONNEL

Salaries ($129,818): One full time project personal (annual salary $42,000) is requested to provide the critical technical support to the project: conduct laboratory experiments, collect field samples, process and do all chemical and instrumental analyses with quality control/assurance, compile all data for statistical analysis, and report to the project investigators (PIs). Salary is projected at 3% annual increase (Grant Year 1: $42,000; Grant Year 2: $43,260; Grant Year 3: $44,558)

Benefits ($49,331): Benefit for the position is projected at 38%. Grant Year 1: $15,960; Grant Year 2: $16,439; Grant Year 3: $16,932.

OPERATING EXPENSES

Supplies ($35,705):
Requested amount will support costs covering field sampling and laboratory analysis supplies that are necessary to carry out the proposed project tasks. We have soil moisture/temperature sensors, data loggers, NH_3 volatilization chambers, and porous ceramic cups for sampling soil pore water. Requested here are only laboratory supplies for all chemical analysis.

Grant Year 1 ($10,676):

- Lab supplies: Gas cylinders, standards, and glassware for plant N and NH_3 volatilization sample analyses: $3,000.
- Chemicals, standards, plastic containers, glassware, and cartridge replacement for analyzer for conducting soil N extractions and analysis for NH_4^+, NO_3^-, and NO_2^-: $3,000.
- Soil characterization by UC Davis Analytical Lab: total $1,800 for twelve samples and six basic parameters (Average costs $25 for each parameter).
- Biochar characterization for pore size distribution, and surface area by a commercial lab is at $220 per sample: total 1,540 for six samples
- Field costs: $1,336 for irrigation, fertilizer, and pesticides etc.

Grant Year 2 ($8,850). Same as Grant Year 1 except that there will be no biochar characterization costs and field costs will be reduced to $1,050.

Grant Year 3 ($10,829). Same as Grant Year 2, plus $1,979 for operation costs in establishing the field experiment in a new site.

Travel ($5,350):

Grant Year 1 ($450). Two project people to attend annual California Plant and Soil conference: total registration fee: $225 each x 2=$450

Grant Year 2 ($2,450). Two research personnel to attend California Plant and Soil conference (Registration fee $450). In addition, one project investigator will attend an industry or a professional meeting such as the U.S. Biochar Conference or the ASA-CSSA-SSSA meeting for 4 days to present research findings ($2,000): registration fee $600; airfare: $600; lodging and per diem: $160 × 5=$800

Grant Year 3 ($2,450). In addition to attend the CA plant and soil conference ($450), one project investigator will attend an industry or a professional meeting such as the U.S. Biochar Conference or the ASA-CSSA-SSSA meeting for 4 days to disseminate research findings ($2,200): registration fee $600; airfare: $600; lodging and per diem: $160 × 5=$800

Indirect Costs: $0.

***** In-kind Contribution ($107,000):**

In-Kind contribution to this project includes the major equipment. USDA-ARS has all essential equipment to support this project, including an Astoria 2 Analyzer ($20,000) for N species ($NH_4^+$, NO_3^-, and NO_2^-) analysis, and a LECO TruMac® CN Macro Determinator (LECO Corporation, St. Joseph, MI) ($65,000) for total soil or plant N analysis. Chambers for NH_3 volatilization, soil moisture sensors, and data loggers are available for the project ($22,000). Waste disposal from N analysis will be covered by USDA-ARS. Charborn LLC will provide biochar without costs. The estimated in-kind support with equipment only for conducting this project is $107,000.